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ABSTRACT

This report reviews America's current energy position. The energy sources studied include oil and gas, coal, nuclear energy, solar energy, and geothermal energy. Each source is analyzed in terms of current use, technology for extracting and developing the energy, research and development funding, and projections for future consumption and production. The study concludes that the inability of domestic sources to meet demands and the rising dependence on foreign supplies predict the end of low-cost energy. (MR)

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AMERICA'S ENERGY POTENTIAL:

A SUMMARY AND EXPLANATION

PREPARED BY

CONGRESSMAN MORRIS K. UDALL, *Chairman*

SUBCOMMITTEE ON THE ENVIRONMENT

FOR USE OF THE

COMMITTEE ON
INTERIOR AND INSULAR AFFAIRS

OF THE

U.S. HOUSE OF REPRESENTATIVES

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LETTER OF TRANSMITTAL

U. S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS,
Washington, D. C., September 20, 1973.

Hon. JAMES A. HALEY,
Chairman, Committee on Interior and Insular Affairs, U.S. House of Representatives, Washington, D.C.

DEAR MR. CHAIRMAN: Since February of this year, the Subcommittee on the Environment has been considering legislation to authorize a multibillion-dollar energy research and development program. In the course of public hearings initiated by the Subcommittee, the Nixon Administration reversed its position from one of outspoken opposition to one of reluctant support and, most recently, enthusiastic advocacy. At all times during the course of the hearings, a bipartisan majority of the Subcommittee indicated general support for such a program; and two of its Members—Mr. Foley and Mr. Ruppe—authored far-reaching legislation in this area.

Following the temporary suspension of hearings in June, I began working with my legislative staff to develop a summary picture of America's current energy position, complete with the kind of technological description that the layman can be expected to understand. The overview contained in the pages which follow is the result, and I hope it will prove to be a useful resource for the Committee Members and our colleagues in the Congress.

An earnest attempt has been made to present a factual study, free of opinion and value judgment. The study was, however, premised on the author's firm belief that this country is in deep trouble on the energy front.

The abundant supply of low-cost energy that has helped support the high level of economic prosperity in the United States will simply no longer be available. Trends of consumption and production imply increasing inability of domestic sources to meet demand, and rising dependence on uncertain and costly foreign supplies. The severity of the situation does indeed justify the widely used term, "the energy crisis."

In fact, this survey confirms the existence of two crises: the first results from an inability to extract known resources at a sufficient rate, already made evident by the gasoline and heating oil shortages. The longer term crisis involves the ultimate exhaustion of our fossil fuel resources and can be expected to occur around the end of the century.

This study, however, focuses not so much on the Malthusian implications of the dual crises, as on the status and outlook of each of our remaining resources, and what options are available to alleviate the developing crises.

Sincerely,

MORRIS K. UDALL,
Chairman, Subcommittee on the Environment.

OIL AND GAS

1. *Current use.*—Oil and gas provide 75 percent of our current energy needs, the relative contribution being as follows:

	Domestic Production	Imports	Total	Contribution to Current Energy Needs (Percent)
Oil (in million barrels per day)	9.5	6.5	16	42
Gas (in billion cubic feet per day)	57	3	60	33

Oil and gas have achieved this predominance because of their low transportation cost, convenient form, and more recently, their advantages with respect to environmental and pollution controls. Together they supply a quarter of the energy required for the electric utilities, over half of the industrial energy requirements, nearly all of the transportation and nonelectric commercial and residential requirements.

2. *Technology.*—The technology of the oil and gas industries is largely developed. Present efforts center on improving recovery rates by secondary or tertiary methods [1] for oil or by hydrofracturing gas-bearing rock to increase the gas-flow rate. Present drilling recovers less than a quarter of the oil and about 50 percent of the gas.

One exotic proposal for greater recovery of gas is Project Plowshare, which is supported by the Atomic Energy Commission (AEC). Gas production would be stimulated by underground nuclear explosions. However, uncertainties regarding possible release of radioactivity or seismic effects would make implementation of such methods subject to considerable criticism. Moreover, the AEC has yet to release standards for permissible levels of radioactivity, which must be done before commercial production can be considered.

A possible alternative source of oil could be developed from the vast oil shale deposits in Colorado, Utah, and Wyoming. Economic extraction of these, however, presents environmental and technical difficulties. For example, the tailings which result from oil shale processing are larger than the original ore, so provision must be made for their disposal. In addition, water requirements for extraction and revegetation may be serious enough to limit production to the modest rate of 1 million barrels per day.

3. *Research and development funding.*—Most funding for oil and gas R. & D. has been from private sources and totaled over $700 million for 1972.

4. *Outlook.*—The prospect that oil and gas will meet the anticipated demands of the future is not encouraging. Due to population

[1] Secondary recovery refers to application of pressure to the oil bearing strata to force out the oil. Tertiary recovery involves burning part of the oil *in situ* to increase production by lowering the viscosity and also increasing the pressure.

growth, rising incomes, and environmental controls, total energy requirements are rising at 4 to 5 percent per year. If such trends continue, demands for oil will rise from its present 16.5 million barrels per day to some 30 million barrels per day by 1985, even if optimistic projections are made for expansion of supplies of other energy sources. Unfortunately, neither domestic supplies nor imports can adequately insure that such future demands can be met.

Domestic production of oil is 9.3 million barrels per day and is already declining, oil from Alaska which might be expected to rise to 2 million barrels per day by 1980 will be of only moderate help, and near term oil shale prospects would appear to be modest.

The final environmental statement on oil shale has been released, so leasing of Government lands may begin in a few months, but several years will be required before pilot production of one quarter million barrels per day can be attained, with full-scale production of 1 million barrels per day anticipated by the middle eighties. Further production increases would depend on technological improvements to reduce water requirements.

Thus domestic supplies are unlikely to exceed 12 million barrels per day. The balance of 18 million barrels per day must be met by imports, some of which must come from the unreliable and politically unstable Middle East. Aside from the serious balance-of-payments strain of such imports, which are projected at $25 to $35 billion per year by 1980, it is clearly unwise to become dependent on a source which might someday be arbitrarily restricted. Even now it appears unlikely that the Middle East, the only area where large production increases are possible, will permit such increases in exports.

Even if such imports are available, shortages will become severe in the next few years due to the lack of refinery capacity. New construction has begun, but will not be completed for 4 or 5 years. Gasoline and heating oil rationing are likely before that time.

The gas situation is similar. If supplies were not restricted, consumption would probably continue to increase at 5 to 6 percent per year. However, like oil, domestic production has peaked, while imports which must be liquefied and transported in special ships, are difficult and costly to obtain. The shortage has been exacerbated by the policy of gas price controls which have held the cost of gas below that of competing energy sources. This policy has encouraged uneconomic or wasteful use, and discouraged new exploration.

Long range projections for both gas and oil are not bright. The National Petroleum Council estimates that reserves of 200 billion barrels of oil, and 1,000 trillion cubic feet of gas exist in the United States. If all oil and gas consumption were to come from domestic production, such reserves would be largely exhausted by the end of the century. If substitutes are not available by then, economic prosperity and national security will be in serious jeopardy.

COAL

1. *Current Use.*—Coal consumption amounts to 520 million tons per year, which is equivalent to 18 percent of our total energy use. The electric utilities consume two-thirds of this and industry takes most of the rest.

2. *Technology.*—Since reserves are adequate for the foreseeable future, concern about the expanded use of coal chiefly centers on extraction and effluent problems. The extraction of coal can be accomplished by either deep mining or strip mining. Deep mining can be both unsafe and unhealthy, plagued by methane and heavy dust pollution. Although the Coal Mine Health and Safety Act represented an attempt to improve working conditions for the underground miner, the occupation remains hazardous. Environmental damage resulting from underground coal mining includes acid drainoff, unstable waste piles, and land subsidence. Such subsidence has already occurred in over 2 million acres of the 7 million undermined acres. Strip mining is safer and considerably cheaper than deep mining but causes greater environmental damage. When hills are strip mined, the overburden is frequently dumped on the downside slope, thus extending the damaged area and leading to the possibility of hazardous landslides. When the coal has a high sulfur content, the exposed seams and spoil banks cause acid drainage which pollutes the streams and rivers. In the West land is flatter, so the landslide problem is avoided, but stripping destroys aquifers and land valuable for grazing, and the limited rainfall of the region leads many to doubt the ability of the mining company to adequately reclaim mined lands. In addition, while coal gasification and liquefaction are attractive possibilities, the immense amounts of water required would put further strain on the available supply.

Unfortunately, environmental damage does not end with extraction. Much of the U.S. coal supply, particularly in the East, has a high sulfur content. As recognition of the damage sulfur oxides can cause has increased, more stringent controls have been placed on such fuels. To alleviate this form of pollution, the pollutants can be removed in the exhaust stacks, in the combustion process, or by some process before the coal is burned. Progress on the first method has been slow and the technology is not adequately developed. If a "fluidized-bed" is used for combustion, much of the sulfur can be trapped before it reaches the stacks. Here air rises from below and keeps the coal particles suspended in a bed of limestone. Sulfur forms calcium sulfate which can be removed as combustion progresses. The Office of Coal Research will build a pilot plant fluidized-bed boiler to demonstrate the ability to burn high sulfur coal well within the legal limits of pollution control.

Most support, however, is directed toward removing the sulfur before combustion. Much of the sulfur in pyritic form can be removed

by washing, but removal of organically fixed sulfur is not so easy. To this end and to convert coal to a more convenient form several techniques are now being developed:

Solvent Refined Coal

Solvent refined coal is produced by dissolving the coal in a heavy aromatic solvent, removing the sulfur and ash by filtering and chemical means, and extracting the solvent by distillation. The result is a low-sulfur solid which can be liquefied at a relatively low temperature of 350° F. A pilot plant to test this process is being constructed at Tacoma, Washington, with support from the Office of Coal Research. Completion is scheduled for 1974, and the necessary data for a full scale demonstration plant can then be obtained. If success is achieved at a reasonable cost, solvent refined coal will reduce both sulfur dioxide and particulate pollution to a low level.

Coal Gasification

With a severe and growing shortage of natural gas, the concept of coal gasification has received considerable attention. Gas is both clean and in a convenient form, while coal is not, so conversion of coal to gas has obvious appeal.

However, the process is difficult. Coal contains less than one atom of hydrogen per atom of carbon, while methane, the chief component of natural gas, contains four hydrogens per carbon atom. Thus hydrogen must be supplied to achieve gasification of coal. This is obtained from the hydrogen in water by combining steam and coal with heat obtained by burning part of the coal. Catalytic actions are required to convert the gas to its final methane form, and sulfur and other pollutants must be removed. Finally, since coal comes in so many kinds and grades, it is unlikely any one process will be best for all coal.

Gas from coal can be either a high BTU gas which is similar to natural gas and has a heat content of 1000 BTU per cubic foot, or low BTU gas which has a heat content of 150 to 200 BTU per cubic foot. Low BTU gas is less costly partly because some of the catalytic actions involved in making high BTU gas are absent, partly because air is used for the combustion of coal to provide heat rather than oxygen, and partly because the low BTU gas conversion process is more efficient, leaving 80 percent of the original energy of the coal in the gas. On the other hand, some of this energy exists as heat in the gas which would be lost if allowed to cool, and transportation costs become prohibitive for distant delivery. Thus low BTU gas will probably be burned immediately, and converted to electrical energy, perhaps in a gas turbine or a combined cycle.[2] High BTU gas can be used directly to augment our scarce natural gas supplies, but it is a more expensive and less efficient process utilizing only 70 percent of the original heat content of coal.

[2] A combined cycle consists of a gas turbine electrical generator and an ordinary steam generator which obtains its power from the exhaust gases of the turbine. Such an arrangement is expected to achieve a higher efficiency than that obtained by a simple steam generator.

Of the gasification schemes only one—the Lurgi method—is presently commercially feasible, and it is restricted to the use of low caking coal. El Paso Natural Gas is now constructing a plant which will implement the Lurgi process and will produce 250 million cubic feet of gas per day. The Office of Coal Research (OCR) together with the American Gas Association (AGA) are currently supporting development of several other systems, three of which are now in the pilot plant stage. Another process is being supported by the Bureau of Mines. Completion of these pilot plants is anticipated by 1976. It is hoped that the best system or systems can then be selected for demonstration plants which might take 5 years more. Commercial plants are hoped to be ready by 1985.

Coal Liquefaction

A companion process to coal gasification is coal liquefaction. Although plentiful energy may someday be obtained from nuclear, solar, geothermal or fusion energy sources, it cannot be used to produce liquid fuel, which is necessary for our present transportation systems. Thus liquefaction of coal may prove crucial in future years as natural oil supplies become depleted.

The coal liquefaction process has received less support than gasification and consequently is less advanced, although a pilot plant has been built by the FMC Corporation under a research program known as Project COED which is funded by the Office of Coal Research. That process converts coal to low BTU gas, oil and char.

3. *R. & D. Funding.*—Much of available funds for coal research comes from the Office of Coal Research. They are supplying two-thirds of the $150 million for the joint OCR–AGA coal gasification program, and $12 million for development of solvent refined coal next year. In addition, half of the supplemental $100 million requested for 1974 by the President has been proposed for further coal research, $25 million of which will go to coal liquefaction, with the rest divided between coal gasification, advanced combustion, and advanced mining and reclamation.

4. *Outlook.*—Coal is a plentiful supply of fossil fuel. Total reserves are estimated at several trillion tons, or thousands of times our present production of 570 million tons per year. However, much is too deep to be economically mined; perhaps 150 billion tons would be currently available. Although such reserves would appear ample in relation to the current production, they are not so ample if required to meet all projected increases in energy demands. For 1985, the projected increase in the total energy demands would require a five-fold increase in coal production which would imply reserves adequate for 50 years at that rate.

Coal will probably not supply significant gas or oil until the 1990's. As noted, the first commercial gasification plants are not expected to be completed until 1985. Such a plant would produce 250 million cubic feet of gas per day, consume 7 million tons of coal and require about 30,000 acre-feet of water per year. The cost of each plant would be about one-half billion dollars. To replace our present use of natural gas with gas from coal would require 250 such plants, and a capi-

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tal investment of $125 billion. Gas from such plants would carry a high cost, several times that of new natural gas, and it might be difficult to raise the necessary capital.

Water requirements may also limit the final production rate. Much of the expansion of coal mining would probably take place in the Western States, and sufficient supplies of water might not be available to produce enough gas to meet the expected gap between supply and projected demand. In addition, the problems of reclaiming mined lands will have to be addressed before the true costs of developing Western coal resources can be fully assessed.

NUCLEAR ENERGY

1. *Current use.*—Nuclear generating capacity is now 19,000 megawatts, which amounts to 5 percent of our total electrical capacity, and about 1 percent of our total energy consumption.

2. *Technology.*—Nuclear power is at once one of the most troublesome and promising new energy sources. Projected electrical demand indicates a five-fold increase by the year 2000. To achieve this increase from oil or gas the United States would have to greatly increase imports since our own production has already peaked and may be near exhaustion by the turn of the century. As has already been mentioned, coal is abundant, but this abundance has to be weighed against the immense environmental damage its use entails. Coal production would have to increase four times current production with corresponding increases in mining damage and sulfur and particulate pollution. Hydroelectric sources cannot have a sizable impact on the exploding demand factor, since most acceptable sites are already in use. If we accept the option of nuclear power, much of the pollution of fossil fuels can be avoided, but other factors must be considered. Since the energy available from nuclear sources is probably ample, the major concern over the coming decades will center on minimizing the environmental impact and avoiding the safety hazards associated with its use.

Specifically, the following questions need to be asked and answered before full development of nuclear energy can proceed: (a) what type of burner reactor is best; (b) whether a breeder reactor is necessary and, if so, what type should be developed; and (c) how can the hazards of thermal pollution, reactor accidents and disposal of radioactive wastes be reduced to an acceptable minimum?

Burner Reactors

Most nuclear power is currently generated by reactors of the light water type (LWR). These are of two types: pressurized water reactors (PWR), and boiling water reactors (BWR). The core, which is cooled by ordinary water, is fueled by enriched uranium where the concentration of the fissionable isotope U^{235} has been increased to 4 percent from the natural concentration of 0.7 percent. The LWR's are being built and run by private sources and are considered a developed industry. They are clean and produce little radioactivity compared with background levels.

On the other hand, LWR's have an efficiency of only 32 percent because of their low operating temperatures. This lower efficiency means that the waste heat rejected to the environment is half again as large as that of fossil fuel plants. In addition, these plants produce waste in the form of nuclear fission products which must be stored permanently. Finally, the possibility exists, although remote, of a disastrous accident.

The most probable cause of such a disaster would be a loss of coolant accident (LOCA) causing the core to overheat and melt. Backup systems for emergency cooling are anticipated to be sufficient, but continuing efforts are being made to increase the margin of safety.

In addition to the LWR's, several commercial plants of the high temperature gas-cooled reactor type (HTGR) are being constructed, with a smaller demonstration plant completed and in the shakedown stage. The HTGR runs at a higher temperature than the LWR, and hence achieves a higher efficiency of 40 percent which is comparable to that of the fossil fuel plants. The coolant is helium, which does not reduce the neutron flux, so the breeding ratio [3] is 0.8 versus 0.6 for the LWR. This difference is important since the long-term requirement of U^{235} is proportional to one minus the breeding ratio. Thus the U^{235} required for the HTGR is only one-half that of the LWR. Also since helium is a nonradioactive gas, the possibility exists of running a gas turbine generator directly, thus making possible a still higher operating efficiency. From the safety standpoint, the HTGR is considered to be less susceptible to a core meltdown than an LWR, since it would take a relatively long time for the massive blocks of graphite used for moderating the neutron flux to heat up.

Against these advantages, the HTGR requires a more highly enriched fuel. Besides being more expensive, this is weapons grade material and the possibility of loss or theft raises serious national security problems. Also, development of the HTGR is less advanced than that of the LWR due to a lower rate of funding in the past, most of which was supplied by Gulf General Atomic.

Breeder Reactor Program

In spite of the considerable supplies of U^{235}, significant support is being devoted throughout the world to development of a fast breeder reactor.[4] Of the breeder reactor candidates, the liquid metal fast breeder reactor (LMFBR) is receiving the most support both here and abroad. The AEC hopes to have a commercial demonstration plant by the mid 1980's. This schedule is behind that of some foreign countries, as the British expect to complete a demonstration LMFBR within a year, and the French and Russians are reported to have them already in operation.

A successful LMFBR would allow us to utilize most of the energy in natural uranium instead of the 1 to 2 percent that present burner reactors use. Since the energy available from each pound of uranium would increase by 50 times or so, we could afford to use the far more abundant low grade ores and thus increase the energy supplies even more. In addition, like the HTGR, the LMFBR would have a higher operating temperature so its efficiency would be higher—40 percent rather than 32 percent—thus reducing the thermal pollution by a third.

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[3] As fission occurs neutrons are released, some of which are absorbed by nuclei of U^{238} or thorium, which then become plutonium or U^{233} respectively, either of which can also be used as fuel. The number of new atoms thus formed divided by the number of atoms split by fission is the breeding ratio.

[4] A reactor that converts more U^{238} or thorium to a fissionable fuel than it uses in the process of fission is called a breeder reactor.

It remains to be seen, however, how soon the LMFBR can become a commercial reality. The LMFBR will be subjected to heavy high energy neutron flux which causes swelling in the fuel cladding and other structural elements due to damage in the lattice structure and accumulation of helium gas. Such swelling may prove excessive for the close tolerances of the LMFBR core, which would require redesign and could reduce the breeding ratio. Moreover, liquid sodium is not an easy material to handle. It becomes radioactive in the core and reacts violently with water and some time may be required for the industry to develop sufficient expertise to handle it.

Safety requirements to assure against a core meltdown (which should certainly be a prime concern) may call for further redesign and lower operating efficiency. Although a LOCA is less likely in a LMFBR than in a LWR, if it occurs a core meltdown is more likely and certainly more damaging. These problems must be overcome before commercial deployment.

The gas cooled fast breeder reactor (GCFR) is likely to be more efficient at breeding than the LMFBR because its coolant—helium—does not absorb neutrons as much as the sodium coolant of the LMFBR so that more neutrons are available for production of fissionable fuel. In addition, the GCFR is an alternative reactor which might provide a backup in the event the LMFBR is not successful. Development of the GCFR, however, is much less advanced because funding has been at a far lower level (the AEC funding has been less than 1 percent of its effort for the LMFBR). In view of the major effort to develop a breeder reactor, critics have suggested that it seems unbalanced to give so little support to this alternative design.

The molten salt breeder reactor (MSBR), like the GCFR, has received restricted support and, in fact, funding was terminated in 1973. As with the GCFR, critics consider it unfortunate that more support is not available to keep open another option.

By changing the core design of an ordinary pressurized water reactor it may be possible to achieve a fissile inventory ratio (FIR)[5] of 1.01 or better. Although the doubling time[6] of this light water breeder reactor (LWBR) would be very long, it would not require further U^{235} after the initial fuel supply. Further, thorium would be the fertile[7] material, which is more abundant than uranium.

Currently, the Shippingport reactor is being converted to test this concept, and should be complete by 1975. After about 3 years of operation, the fuel should be ready for reprocessing and the resulting FIR can be ascertained. An FIR of greater than one, even if it produces no excess fuel, would imply sufficient energy reserves for thousands of years at the present rate of use. The LWBR has the obvious advantage that it utilizes the technology of the LWR which is currently in operation. Also, present PWR's can be backfitted to become LWBR's.

[5] The fissile inventory ratio is defined as the amount of fissionable material available after the core is burned divided by the initial amount of fissionable material in the core. This differs slightly from the breeding ratio which is the instantaneous rate of new fissile atoms produced divided by the atoms fissioned.

[6] The doubling time is the time required for a reactor to produce sufficient new fissionable fuel such that its total inventory of fissionable fuel is twice the initial amount of fissionable fuel.

[7] Fertile material, while not fissionable itself, can be converted to fissionable material by absorption of neutrons.

Enrichment Capacity

Since the LWR's are designed for fuel with 3-to-4 percent concentration of the fissionable isotope, U^{235}, natural uranium, which contains only 0.7 percent U^{235}, must be enriched before the reactors can burn it. It is important, therefore, to insure adequate enrichment capacity. The AEC believes that their three gas diffusion enrichment plants are adequate until the early 1980's, but additional capacity will then be required. Since it might take 6 or 7 years for construction, the decision must be made soon to build new plants.

The question is what type of enrichment plant should be built and who should build it? The AEC would like private industry to assume responsibility but industry must first consider it a profitable venture. The difficulty is that a gas diffusion process requires an enormous supply of energy (which can be expected to rise in cost) compared with a gas centrifuge process. The latter, however, is not yet a proven process. Since either plant involves capital investment of several billion dollars, it is possible that only the Government will be willing to accept the risk involved.

Waste Disposal

As nuclear energy rapidly expands in the coming decades the difficult problem of containment of nuclear wastes will likewise expand. These wastes can remain hazardous for thousands of years and some method for their permanent storage must be devised. Clearly in the past the care and effort in this realm have been insufficient. At the Hanford Repository one storage tank for liquid radioactive waste was found to have been leaking for months, a fact that was overlooked through poor management techniques. Even if greater care is exercised for storage of commercial wastes, some method of permanent storage is needed soon. Presently conceived alternatives are solidification of the liquids and subsequent burial in salt beds, salt domes, water-free igneous monoliths, ocean trenches, or in shale or limestone deposits.

Fusion

Fusion power, another form of nuclear energy, may be available if heavy forms of hydrogen—deuterium or tritium—can be combined to form helium. The energy available from this source would be inexhaustible if deuterium alone suffices, and larger than our fossil reserves if tritium is required. Radioactive wastes would be produced, but would be much less dangerous than those produced by nuclear fission.

Thus fusion, if possible, has been seen as a clean, unlimited source of power for the future. This may be, but there are a few caveats to attach to the attractive promises of nuclear fusion. The technology of controlled fusion power is immensely complex, and three barriers must be overcome—scientific feasibility, engineering feasibility, and economic feasibility. The first is now being researched, and hopes are high for a successful demonstration of scientific feasibility by 1980. Even if success is achieved awesome technological problems must then be overcome. For instance, it is not yet known what effects the intense, high energy, neutron flux will have on the structure. The entire apparatus may have to be periodically replaced in an uneconomically short time. It must be remembered that it has taken over 30 years from scientific feasibility to significant power generation from nuclear fission, and fusion is a much more complex and less understood subject.

3. *R. & D. Funding.*—Nuclear research is currently receiving top priority by the Government. The LMFBR alone is receiving $270 million for 1973 and $320 million is requested for 1974. Other support includes $32 million for emergency cooling systems, $25 million for the HTGR, $15 million for waste disposal and $18 million for the LWBR, $95 million is earmarked for fusion research of which $53 million is slated for the magnetic confinement concept while the balance is for laser-induced fusion. Part of the latter, however, is considered to be for military application.

4. *Outlook.*—Although nuclear energy is coming onstream at a slower pace than originally planned, the rate of installation is anticipated to rise sharply in the coming years. Proponents argue that initial high capital costs are more than outweighed by the absence of chemical pollutants and the low costs and availability of fuel relative to fossil-fueled plants.

The AEC estimates supplies of probable and potential uranium fuel as follows:

Dollars-per-pound cost of U_3O_8	*Thousands of tons of U_3O_8 Available*
$8	700
10	1,000
15	1,500
30	2,400
50	8,400
100	17,400

These are considered to be conservative figures since exploration activity has been concentrated in the present producing areas which make up less than 10 percent of total regions where uranium signs occur. Also, it has been the history of other minerals that reserves at any given time are underestimated. Thus, it is not unlikely that true reserves are many times as abundant as the AEC estimates.

Since each incremental dollar-per-pound in the cost of uranium oxide converts to 0.06 mills per kilowatt-hour, even with these conservative estimates we would have over 8 million tons of fuel available by accepting a modest rise in fuel costs of only 2.5 mills per kilowatt-hour. This is equivalent to about 50 billion kilowatt-years if burned in LWR's or twice that if burned in HTGR's. Accepting the AEC estimates of an installed nuclear capacity of 500,000 megawatts by 1990 and a load factor of 0.75, such reserves are adequate for 150 to 300 years at the 1990 rate of use.

SOLAR ENERGY

1. *Current use.*—Its potential long underrated, solar energy is quickly gaining advocates in the scientific community. It is both a clean and renewable source with a potential for hundreds of times our present requirements. However, except for hydroelectric power, which can be considered an indirect application, utilization of this source is almost nonexistent; hydroelectric power constitutes about 15 percent of our present electric capacity.

2. *Technology.*—Although solar energy is abundantly supplied, it is so thinly distributed that its efficient collection presents significant technological and economic problems. Further, it is an intermittent source subject to nighttime and weather interruptions thus necessitating the development of an economical and practical method to store the energy.

Direct Conversion

Direct conversion of solar energy is possible by allowing the solar radiation to act as a heat source (photothermal) or by using photocells which produce an electric current when exposed to light (photovoltaic). Both methods have been proposed as the energy source for central power stations. Since the efficiency of a thermal powerplant increases with increasing temperature, thermal conversion requires concentrating the solar radiation by optical focusing. One method which achieves very high temperatures involves many steerable mirrors, or heliostats, to fix the image of the sun on the thermal collector. The capital costs involved, however, are extremely high and the system requires a clear sky to operate. A cloud cover or even a light haze will scatter most of the solar energy away.

A more promising technique involves a flat collection device together with a thermal receptor made of selective coatings which transmit the visible light but not the infrared. Such a configuration would be a passive arrangement making heliostats unnecessary, and could operate on cloudy days, since radiation from all the sky is collected. This method is expected to produce working temperatures of around 350° F. Power production during periods of heavy clouds or nighttime would be accomplished by storing heat in a reservoir of eutectic salts. Although the capital costs of such a system are not yet clearly in focus, the system's potential could be evaluated by construction of a pilot project costing about $4 million over the next 3 years.

Photovoltaic systems suffer from extremely high capital costs—about $20 per watt—for the photocells alone. This must be reduced by a factor of 50 before they could be economically competitive. In addition, like the photothermal concept, methods for storage for night or heavy cloud periods must be devised. To overcome this deficiency, it has been proposed that a photovoltaic power station be assembled in a synchronous orbit in space which would beam the collected energy

to Earth in the form of microwaves. To make such a project economical, a successful space shuttle must be achieved, a space tug would need development, and photocell costs must be vastly reduced. It would seem that such a project will be economically viable only in the distant future, if then. Further, it is not yet known what effect microwave radiation has on human health, and such hazards might vitiate the whole concept.

Small Scale Applications

Direct use of solar energy may have immediate application for heating and cooling of residential and commercial buildings. Since such needs currently consume more than 20 percent of our total energy requirements, success in this area would eventually make a substantial contribution toward alleviating the energy crisis.

Possible construction methods would include heat collectors on the southern exposure of a building through which a working fluid would carry heat to a central storage medium, either water or a eutectic salt. Temperatures of 200° F. or higher could be achieved which would be sufficient for hot water, space heating, and possibly space cooling by an absorption unit. Although the capital costs would be high, the same collector and storage unit would be used for all three applications. Estimated life cycle costs would then be comparable to present fuel costs in much of the country, and more favorable to the extent that fuel costs rise in the future.

Significantly, not much technological development is needed to achieve such advantages, but it would be useful to start pilot projects to improve the design, efficiency, and acceptability of such systems. Until such projects are actually in use it will not be known what reliability of the system will be required, what unforeseen accidents might occur, how best to store heat or cold, and the extent to which backup systems are required to protect against long cloudy periods.

Proponents of solar energy have suggested governmental actions to accelerate its acceptance by architects, builders, financial institutions, and the consuming public. Such governmental actions could include collection of necessary meteorological data, updating the building codes to permit solar collectors, subsidies to reduce early development costs, and possible tax changes to encourage residential and commercial installations, all backed by educational efforts to shift emphasis from a consciousness of initial costs to one of life cycle costs.

Indirect Solar Applications

The indirect effects of solar energy such as photosynthesis, wind energy, ocean thermal gradients and conversion of organic material should not be ignored. Although none of these applications is likely to cure the energy shortage in the foreseeable future, such minor sources of energy have the potential to mitigate the crunch. In addition, there is hydroelectric power which is a fully developed industry.

Photosynthesis

Solar energy is stored naturally by photosynthesis, and can be reclaimed by combustion. The deficiency of growing and burning plants

lies in the very low efficiency of photosynthesis. Most forests fix less than 1 percent of the solar radiation, which implies requirements of over 1,000 square miles to power a 1,000-megawatt plant. Growing grain for alcohol production suffers the same defect, and becomes prohibitively expensive. In any case, there is not enough excess crop land to produce a significant amount of such fuel. Indeed, just this year all acreage restrictions have been released to meet food and fiber requirements.

Wind Energy

The winds which are powered by solar heating contain energy roughly comparable to our present energy consumption. However, this is spread so thinly that it is questionable that significant production of energy can ever be obtained. In addition, the source is intermittent, and storage or backup systems are required for reliability. Still, such systems could be important for special localized situations.

Ocean Thermal Gradients

One proposal is to take advantage of the ocean itself as a solar collector by using the thermal gradients of the sea to power a low-pressure turbine, using a secondary working fluid such as ammonia. Capital costs of $100 to $200 per kilowatt have been calculated, which are less than the costs associated with current nuclear reactors. The concept has the potential of a renewable source of energy many times our current use, which will not significantly affect the environment. The idea is intriguing, but the location of the plant would be too distant from consuming centers to transmit the electric power directly. Thus the electricity would be used to electrolyze water to hydrogen and oxygen and pipe the hydrogen to shore where it could be burned like natural gas. The cost of such gas would be higher than new natural gas is now, but as shortages drive gas prices higher, it may become economical in the future. Large-scale use of hydrogen would require some technological adjustments such as modified burners and a new pipeline system. Present pipelines would suffer embrittlement if used for hydrogen.

Conversion of Waste Materials

Municipal or agricultural waste materials can be converted to methane gas or even oil by bioconversion using solar radiation to supply the necessary warmth. Such a process would also reduce the solid waste disposal problems now facing municipalities. The total energy potential would be small (probably not more than a few percent of our projected usage), but is considered sufficient to warrant development.

3. *R. & D. Funding.*—Present funding by Government agencies for solar energy R. & D. has been minimal. NSF is supplying $4 million for 1973, but this will increase to $15 million in 1974. Private interests are supplying other scattered amounts.

4. *Outlook.*—Although costs are likely to be high, the clean, renewable and abundant nature of solar energy will provide strong incentive for extensive utilization in the future.

Small-scale solar collectors are likely to become available soon, but near term widespread use is unlikely since present buildings already have installed heating and cooling capacity, and would require major modifications to switch to solar sources. With sufficient support, however, a significant fraction of new construction may utilize solar energy for hot water and space heating and cooling requirements by the end of the century.

Solar central power stations are unlikely to contribute significantly to our electric power capacity until competing fuel costs rise substantially, or environmental considerations restrict construction of alternate sources. At that time, photothermal solar power could be developed to meet a substanial portion of our electrical requirements. Proponents of solar power maintain that funding and action are needed now to obtain necessary data and experience so that full scale construction can begin as economic considerations permit.

As natural gas reserves become exhausted it is possible that the United States may shift to a hydrogen economy with the hydrogen being obtained from electrolysis of water using electric power. Hydrogen can be shipped by an appropriate pipeline system and can be used by industry in place of natural gas, although it would not work for present residential users. The intermittent nature of direct solar conversion for wind power or the distant nature of ocean thermal power would then not be a disadvantage since energy could be shipped or stored in the form of hydrogen gas. Such a development might occur by the end of the century.

GEOTHERMAL ENERGY

1. *Current use.*—Geothermal energy is now being tapped in California where its present capacity is about 400 megawatts, or about 0.1 percent of our present electric power capacity.

2. *Technology.*—Although the flow of heat from the Earth's interior is only one-thousandth that of the solar input, the heat accumulated over past ages is so large as can be considered limitless. Geothermal energy can be divided into three parts: Steam dominated, hot water dominated, and dry hot rock resources.

Steam Dominated

A small fraction of geothermal energy can be tapped directly by drilling in steam domes like the geysers area in California. When ground water comes in contact with hot rock, and the resulting steam is trapped at higher levels by impermeable layers, it can be drawn off as dry steam. Such features tend to occur in areas near recent volcanic action or where tectonic plates are interacting, and are concentrated in the Western States of the United States.

How long production can be continued from geothermal wells is not known, but the fields in Larderello, Italy, have been producing since 1904. These wells gradually decline in production and new wells must be drilled to maintain the flow. The cause of the decline may be either depletion of the resource or deposition of minerals as the water is boiled off.

The environmental impact of dry steam geothermal energy is not serious; indeed, some environmentalist groups consider it to be the cleanest source of energy around. However, since the operating temperature of the geothermal steamplant is very low (from 300° to 500° F.), the efficiency is also low (15 to 25 percent). This means that the thermal pollution is as much as six times greater than fossil fuel plants. Also, the steam contains pollutants such as hydrogen sulfide or boron which should be removed or reinjected into the ground. The drilling and venting can be very noisy and mufflers will be needed if production is near populated areas.

Hot Water Dominated Sources

Hot water dominated sources are more abundant than the dry steam type, although they occur at lower temperatures. The hot water type can be utilized by either allowing the water to flash to low-pressure steam at the surface or to flow through a heat exchanger which powers a turbine with a secondary working fluid such as isobutane. If the former method is used, considerable effort is needed to insure that pollutants are not released to the environment. The hot water resources tend to be very saline and highly corrosive, and while it is possible that

the purified effluent can serve as a source of water, such use might then cause land subsidence. Even if a secondary fluid is used to run a turbine and the hot water reinjected into the ground, corrosion and scaling can clog the heat exchanger. Currently there are no commercial geothermal hot water plants in this country. One well was drilled in California, but the heat exchanger and well casings were soon clogged by scaling and the powerplant was not built.

Hot Rock Resources

The largest source of geothermal energy consists of hot dry rock which, if it can be extracted, at least has the potential for all our energy needs for centuries. Devising an economic method of extraction that will avoid polluting the environment is however, the principal problem to be overcome. The method proposed is to fracture the hot rock either hydraulically or by nuclear devices and pass cold water through the cracks. The resulting hot water drawn off at the top of the crack is then run through a heat exchanger of a thermal plant and reinjected at the bottom of the fracture zone. Hopefully, as the rock is cooled it contracts and the fracture extends bringing more hot rock into contact with the water. Although hydraulic fracturing is a developed technology in respect to increasing natural gas flow, less is known of its behavior with hot deep rock.

3. *R. & D. Funding.*—At present development of the dry steam geothermal sources is supported solely from the private sector. Government funding for surveys and development of hot rock resources has not been at a high level, amounting to $3 million in 1973 with $11 million anticipated for 1974, of which the National Science Foundation supplies $2 million, the Department of the Interior $4 million, and the AEC the rest. This is an experimental area where greater funding will be required to answer the key technological questions.

4. *Outlook.*—The geysers area in California where commercial development is now occurring is expected to have a capacity of from 2,000 to 10,000 megawatts, while the United States as a whole might have from 10,000 to 100,000 megawatt capacity from dry steam sources. However, since most known geothermal resource areas (KGRA) are on Federal land, development will be limited until the Government permits leasing, which is being delayed until an environmental impact study is completed.

Hot water dominated sources have a still larger capacity, but it is not yet known whether the technological difficulties of such corrosive water will restrict its use.

The hot rock resources may ultimately have enormous capacity, but like the hot water resources it is not yet known if the technological difficulties can be overcome. Preliminary drilling at Los Alamos, however, is encouraging, and it is hoped to achieve larger fractures and extraction of thermal heat in a few years.

NOTES ON ENERGY CONSERVATION

A national effort of energy conservation would help mitigate the impending shortages. Such an effort could be encouraged by a nationwide publicity campaign, tax or price incentives, or possible legislation. Conservation can be accomplished by more efficient conversion methods, more efficient use of energy in producing goods and services, or by using less goods and services that require energy.

1. *Conversion methods.*—Energy used to produce electricity comprises 25 percent of our total demand, and is projected to increase to 50 percent by the end of the century. Thus, any increase in the efficiency of conversion will have a major effect on our total energy demands. Modern fossil-fueled steamplants with input temperatures of about 1,000° F. achieve efficiencies of 42 percent, which is almost two-thirds of the maximum efficiency permitted by the laws of thermodynamics for that input temperature. Further improvement in efficiency would depend on achieving higher operating temperatures and pressures, a result which is difficult to accomplish economically with present materials. However, higher temperatures can be used with a gas turbine which, when combined with a steamplant powered by the turbine exhaust heat, is anticipated to achieve efficiencies of 50 percent or more by 1980.

Another conversion method to consider is magnetohydrodynamics (MHD) which produces electricity by forcing a hot ionized gas past a magnetic field. When used as the topping cycle for a steam powerplant, efficiencies of 50 to 55 percent might be achieved. High sulfur fuels could be used, since the sulfur would be removed by combining with the ionizing "seed" material.

There are, however, technical roadblocks to successful development of MHD. So far, models have achieved only short lifetimes, and difficult problems exist with respect to high temperature electrodes as well as high temperature metal erosion and corrosion.

Development of fuel cells would be another method of achieving high efficiency of conversion to electric power. Fuel cells which catalytically consume fuel to produce electricity could be expected to achieve efficiencies of 60 percent, and would complement the concept of a hydrogen economy should that develop. However, in spite of substantial governmental and private funding for fuel cell research and development, low-cost economical fuel cells have not yet been achieved.

2. *Efficiency of energy consumption.*—The transportation sector of the economy accounts for approximately 25 percent of the total energy consumed, nearly all of which is supplied by oil. Higher gas prices, gas taxes, or gas rationing would lead to greater gas economy, by encouraging trends to smaller autos, fewer amenities such as automatic transmissions and air conditioners, and more efficient engines. Greater engine efficiency might be obtained by shifting to diesels where appropriate, by perfecting stratified charge combustion, or more novel modi-

fications such as using the kinetic energy of a flywheel to assist in acceleration, thus permitting a smaller, more efficient engine, and possible recovery of energy normally lost in braking.

The residential and commercial share of total energy consumption amounts to 32 percent if both direct fuel uses and electrical power uses are counted. The major requirements are for space heating and cooling, water heating, refrigeration, and cooking. Greater attention to life cycle costs as opposed to initial costs would help. Actions encouraged by such emphasis would include greater initial insulation, greater attention to efficiency of appliances (some air-conditioners are more than twice as efficient as others), use of fluorescent lighting instead of incandescent lighting, and consideration of thermal storage methods to reduce peak requirements. A truth in energy bill, besides giving incentive to manufacturers, would help to make consumers more energy conscious. Finally, if energy costs increased with increasing use, there would be a greater incentive to reduce consumption.

Energy consumption in the industrial sector accounts for approximately 43 percent of total energy demand, if electricity consumption is included. Although much of the industrial sector is already utilizing energy in a fairly efficient manner, higher fuel prices might encourage retirement of outdated inefficient plants. Considerable savings could also be obtained by emphasizing recycling materials. Current laws discourage such reuse since depreciation and depletion allowances favor new production and are not available for recycled materials. Also, freight rates are higher for waste materials than for new production thus further discriminating against recycling.

3. *Conservation by reducing demand for goods and services.*—This option implies a reduction in the GNP, and would probably be the least popular method of conserving energy. Still, to the extent it would reduce the "throwaway" and "planned obsolesence" aspects of the economy, we would all benefit.

It should be realized that conservation efforts, even if immediately implemented, are unlikely to result in substantial savings right away. Much of the effort can only be directed at new installation; replacement of inefficient generating plants, poorly insulated houses, outdated appliances, and autos with poor gas mileage will take many years to achieve. Yet, if we do not begin the conservation effort until circumstances force an energy reduction, it will be too late.

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